ARCHITECTURE AND IMPACT OF AN OPEN, ONLINE, REMIXABLE, AND MULTIMEDIA-RICH ALGEBRA 1 COURSE

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ABSTRACT
Less than half of the students in the United States graduate from high school and are ready to take college-level math courses. Many years and varieties of remedial math programs have failed to dramatically improve outcomes, especially at scale. The question we face is whether technology in general, and open educational resources in particular, might offer some solutions for improving math scores across the nation. Herein, we describe the work of the Monterey Institute for Technology and Education, and specifically the design and early evidence of impact of their multimedia Algebra and Developmental Math resources. We believe that the structure and function of these open educational resources can effectively meet the diverse needs of the nation's math teachers and learners, perhaps paving the way to more personalized teaching and learning practices.

KEYWORDS
OER, remediation, developmental math, remixable, multimedia

I. INTRODUCTION

A. The failure of math education in the United States

Math education has become a national calamity for the United States of America. The national averaged freshman graduation rate for public school students in the United States for the class of 2008—09 was 75.5 percent, with one state reporting its graduation rate as 56.3% [1]. While this failure can be attributed to a number of non-academic as well as academic causes, there is widespread agreement that many students fail to graduate due to poor performance in basic skills, especially in math [2, 3]. Furthermore, of those who successfully graduate, approximately 34% are still deemed insufficiently prepared to begin college-level coursework (43% in community colleges), relegating many students to developmental, non-credit-bearing courses [4, 5]. Students pay dearly for these courses, both financially and in terms of the blockade to their educational aspirations. Institutions also spend substantial resources on developmental courses, yet persistence rates are low and most referred students fail to ultimately achieve a higher-education credential [5-7].

The last decade has seen a dramatic expansion of effort to improve math outcomes at the secondary level, yet graduation rates remain low [8], and we have not seen dramatic improvement in the math preparedness of students entering post-secondary education [9]. And of course these changes do nothing for the substantial—and growing—numbers of adults who are returning to higher education for retraining or enhancement of their professional skills [4]. Institutions differ substantially on both their expectations regarding the math competency of incoming students as well as their own capacity to remediate as deemed necessary [10]. Students who find themselves referred for remediation are in a sort of limbo: by age and prior accomplishment they should be in higher education, yet their actual skills render them unfit to pursue credit-bearing courses [11]. It is very difficult for students to manage this challenge

independently, but there is no easy way to assign responsibility for this problem to any particular institutional parties [5].

Fortunately, there are a number of countervailing trends that give some cause for optimism. For example, research has shown quite conclusively that students learn best if the content is deemed to be relevant and engaging [12]. These findings have shifted much of the interest in innovation away from identifying the "best" resources to instead experimenting with many different types of resources, supporting technologies, pedagogies, and curricula. Also, technical infrastructure, while still lagging in many parts of the educational sector, is improving, making it easier for educators to leverage rich media and interactive digital tools for learning, many of which are likely to be significantly more engaging to the students. There are many valid concerns among educators and students regarding the proper role of technology in the classroom, but more and more institutions are supporting their teachers through technology and seeking ways to expand upon the opportunity it presents [13; see also the many references tracking technology use and integration available at: http://www.educause.edu.]. Finally, we are seeing the emergence of open educational resources (OER), which are free materials that are generally distributed digitally, usually via the Internet, and licensed for localized customization and adaptation [14]. While the promise of ubiquitous, high-quality OER has not been realized, the existence of OER has nonetheless shifted perceptions away from mass adoption of singular, static resources and towards consideration of the many ways to meet the individualized needs of specific learners and institutions [15, 16].

The question we face is whether technology in general, and OER in particular, might offer some solutions for improving math scores across the nation.

B. The promise of OER

Open educational resources were first defined at a UNESCO convening in 2002 [14]. Since then, they have captured the imagination of students and educators around the world, and received funding from several leading philanthropies, most notably the William and Flora Hewlett Foundation, where OER has been a strategic priority since 2006. More recently, OER has found support from state legislatures as well as the federal Dept of Education. These successes have led to the community of OER advocates recently discussing the process of moving OER "into the mainstream."

A number of organizations have been actively producing or supporting OER for many years now. For example, Connexions (http://cnx.org/), CK12 (http://www.ck12.org), Curriki (http://www.curriki.org), Flat World Knowledge (http://www.flatworldknowledge.com/), the Open Courseware Consortium (http://www.ocwconsortium.org/), Merlot (http://www.merlot.org), PhET (http://phet.colorado.edu/), and the Monterey Institute for Technology and Education (MITE) (http://www.montereyinstitute.org/) have all contributed substantial quantities of resources to the OER pool. Other initiatives have become more aligned with the OER effort over time, such as LearnNC (http://www.learnnc.org/), the National Science Digital Library (http://nsdl.org/), Teachers Domain (http://www.teachersdomain.org/), and other public media producers, and others. And there are relative newcomers that have dramatically increased the awareness of OER with their success, such as Khan Academy (http://www.khanacademy.org/), Saylor.org (http://www.saylor.org/), and MITx (http://mitx.mit.edu/). The OER effort is international in scope, with projects such as Siyavula http://projects.siyavula.com/), Peer to Peer University (http://p2pu.org/), Wikieducator (http://wikieducator.org), European Schoolnet (http://www.eun.org), and others playing important roles now and from the beginning. And various supporting organizations continue to catalyze the OER effort, including Creative Commons (http://creativecommons.org/), ISKME (http://iskme.org/), SREB (http://www.sreb.org/), and other non-profit or governmental groups.

However, this diversity of activity within the OER frame is as much a challenge as it is a source of strength. For the typical educator or learner, the term "OER" does not carry much meaning. Furthermore, the OER community continues to occupy itself in debates around proper licensing, technical formats, sustainability models, and other topics which seem esoteric even to those who have taken an interest in the efforts [17]. When seeking OER, a potential user encounters a dizzying array of resources, supporting technologies, and conflicting claims which can result in a sort of paralysis and bolster a rational concern

that perhaps OER, however defined, are not quite ready for mass adoption. For educators and others who already find themselves stretched for time, burdened with conflicting expectations, and unsupported in their efforts to innovate, OER seem like another problem to solve rather than the solution they are purported to be.

C. About MITE

In addition to acting as a facilitator between academia, business, and government, MITE pursues the following overarching objectives:

- Enable free, personalized learning for every person.
- Produce resources that are cutting edge and of demonstrable quality.
- Build a community of educators and institutions who inform and are empowered by our work.
- Sustain the enterprise in the face of changing technical and financial circumstances.

In order to achieve these objectives, MITE instituted a unique organizational structure:

First, MITE established a membership organization, called the National Repository of Online Courses (NROC), which serves educational institutions and other interested agencies. Member institutions gain unlimited use of MITE's materials along with service and support; more importantly, they become co-creators of new content, including the math content described here.

Second, MITE distributes most of its resources for free to individuals via a website called Hippocampus. Hippocampus also offers various tools for institutions, teachers, and learners to manage the learning materials on the site and customize their implementations.

Third, MITE pursues a variety of related activities, including advocacy, professional development, and research, in order to build community and capacity around the use of the materials, as well as to better understand which materials and implementations seem most effective for learning.

MITE is supported by the NROC network as well as several major philanthropic foundations, including the William and Flora Hewlett Foundation, the Bill and Melinda Gates Foundation, and the MacArthur Foundation.

D. Simplifying the OER meme

In actuality, most of the problems often attributed to OER are actually problems of digital resources in general. Most schools are not equipped to provide one-to-one technologies for students, and most teachers have neither the capacity nor the permission to keep up with the rapidly evolving — and growing — corpus of digital educational resources. State and district policies are often based around adoptions of specific types of media, and those media are required to meet a variety of legal and curricular demands that few publishers can meet. It is possible to work around these constraints, but then teachers and schools subject themselves to risk and liability, especially if learning outcomes decline, as might be expected when a new pedagogical approach is tried for the first time.

Is there a way forward with OER that ameliorates rather than exacerbates these challenges? To answer this question, we need think differently about the manner in which educational resources are produced and distributed. This thinking requires reconsideration of every facet of the production process, from the structure of the publishing organization, to resource planning and design, to dissemination and implementation among a diversity of institutions. The Monterey Institute for Technology and Education (MITE), founded in 2003, embraced this challenge as part of a its core mission and continues to strategize around possible solutions. Specifically, MITE sought to identify a model for developing and distributing educational resources that:

- provides learning activities to support an efficient path to credit-bearing courses,
- offers multiple modes of instruction,

- supports multiple curricular standards,
- allows for flexible course configurations with a collection of learning objects,
- leverages the power of digital media.

Most importantly, we wanted to be sure that any resources we create would encourage and enable experimentation and innovation without the concomitant breakdown of quality assurances and curricular relevance.

II. A "COMMUNITY GUIDED" DEVELOPMENT APPROACH

In building an Algebra 1 course, followed by a Developmental Math program, MITE iterated its way to an approach that hybridizes a traditional publishing model with many of the new capacities of digital media. To begin, MITE extensively researched the existing educational products and publishing pathways, noting quality features as well as opportunities for improvement. MITE also conducted extensive numbers of focus groups to involve the target users (people and institutions) early on in the development process. Like a traditional publisher, MITE retains teams of experts to bring together the underlying technologies, the user-facing product designs, the curricular structures, and professional development supports. Unlike a traditional publisher, MITE involved its membership continually throughout the design and development process, and across all aspects of the media production. As a result, MITE was able to build and market the Algebra and Developmental Math resources simultaneously, ensuring that the resources would meet user needs, and that those users would be ready to adopt them. We dubbed this approach a "community guided" development model.

The extensive involvement of the NROC membership (http://www.montereyinstitute.org/nrocnetwork/members.php) allowed us to ascertain a number of key criteria that should inform most, if not all, production efforts for (open) educational resources. For example, for Developmental Math, we held 68 roundtables consisting of over 720 students, instructors, and administrators, collectively representing 153 academic institutions in 28 states. Administrators and faculty who participated helped us to determine shortcomings of existing teaching materials and better understand administrator and faculty use cases. Students who participated helped us to learn what digital learning materials they were already using and what student use cases we should be mindful of. All participants gave continuous feedback on products in development and readied themselves for use and adoption of the materials.

The highlighted findings from these conversations with the community were as follows:

For administrators:

- Professional development is essential for supporting teacher success.
- Few instructors and institutions are satisfied with existing methods or digital options.
- Existing digital products are too expensive, offer inflexible curricula, and are locked in proprietary management systems.
- High value is placed on flexibility, affordability, and multiple pathways for learners.

For students:

- Keep it simple: struggling students and English language learners value simplicity.
- Real-world examples and application are key to engagement.
- Puzzles, animations, simple illustrations, and problem sets are important.
- Humor, esoteric example, and idioms trip-up or confuse struggling students, especially English language learners.

Examine:http://www.nrocmath.org/cms/wp-content/uploads/MITE_WhitePaper-Focus-Groups-Summary.pdf for further details of these findings.

III. A PROPOSED SOLUTION

We analyzed the guidance we received from the community and then considered how we might build resources that meet those criteria. We were also mindful of the fact that the resources would have to work where teachers and learners actually use them, which means they would need to be modular (to ease adaptation and customization), platform independent, and supportive of a variety of instructional models, including online, offline, and hybrid educational settings.

One of the most important decisions we faced was settling on an appropriate "grain size" for the resources. In other words, given that we were building modular resources, how comprehensive or focused should each of the modular units be? Our community informed us that alignment to state or Common Core (http://www.corestandards.org/) standards was a key attribute for any resources they might use; thus, we knew that we had to produce resources that could be rearranged without losing this property. We chose to build all of our resources at the topic level. The topics, in turn, are based on a complete taxonomy of learning objectives, which roughly correspond to the individual expectations and standards set by the various state frameworks and the Common Core. There are 68 topics for Algebra 1, contained within 12 units and 26 lessons, and covering 170 learning objectives. There are 124 topics for Developmental Math, contained within 18 units and 55 lessons, and covering 370 learning objectives.

A closer look

Having settled on a grain size, we proceeded to build a suite of resources for each topic. The goal was to provide a menu of options for engaging with the content, subject to personal preferences, pedagogical designs, and any other variables that might come into play for either the teacher or learner.

Thus, for each topic, we produced:

- interactive problems, organized as warm-up, benchmark (formative), and summative collections
- a video presentation
- video-based worked examples
- textbook sections, including multimedia elements.

Furthermore, we produced a variety of additional resources at the unit level, consisting of:

- virtual, video-based, interactive tutors
- suggested (group) projects
- interactive puzzles and games.

These resources are provided as complete collections, covering all of the learning objectives for Algebra 1 or Developmental Math; however, their modular design means that they can be rearranged and subdivided as desired. In the OER community, we would say that these resources are "remixable," to borrow a term from music arrangement where new music is assembled from samples of existing music, as opposed to creating new music from scratch. This property stands in contrast to monolithic resources, which are often tightly scripted and coupled, and therefore not amenable to being taken apart and reused in different ways. Indeed, we presume that most users of these resources will only use a subset of what is available.

The resources are available to every person for free on the Internet via the Hippocampus website (http://www.hippocampus.org/). Hippocampus is designed to function as a library for multimedia resources; thus, we distribute content from a variety of other publishers, including the University of California, Khan Academy, PhET interactive simulations, and more, in addition to our own content. Hippocampus also functions as a personalized media player. Users of the site can create and store customized playlists using any and all of the resources. Institutions that are members of the NROC Network (http://www.nrocnetwork.org/) can also request to have a branded Hippocampus site where they can customize the contents as well as many elements of the design.

Most members of the NROC Network prefer not to access the resources via the Internet. MITE provides

these institutions with all of the resources in whatever form they need so that they can install them on their learning management systems (LMSs) or other repositories. For many institutions, gaining access to the resources in this manner is the key incentive to joining the NROC Network; however, many institutional participants discover that they get even more value out of their involvement with the community, especially when it comes to sharing knowledge among peers and providing guidance to ongoing resource developments. It takes considerable time and expertise to support the institutional uses of the resources; fortunately, the financial contributions from the sustaining NROC Network members are now sufficient for MITE to operate close to a break-even level. MITE is one of the only OER projects to have achieved financial self-sustainability, giving assurance to both individual and institutional users that the resources will be maintained and distributed for the foreseeable future.

IV. IMPLEMENTATIONS AND IMPACT

The NROC Algebra 1 course was published in mid-2011. The Developmental Math program is partially released as of mid-2012, and will be fully published by the end of the year. While publication of these resources is a significant achievement, this is only one step toward the overarching goals of encouraging pedagogical innovation, improving educational access, and ultimately enhancing learning outcomes. Our community made it clear that they wanted resources that accommodated their diverse needs and aspirations, as unpredictable as they may be. As such, we knew that we needed to work with our institutional partners to better understand the contexts and strategies in which our resources might be deployed, for better or worse. While we obviously hope that our resources will improve learning outcomes in all situations, we do not presume this will be the case. Learning is a complex process, and our educational programs involve many different people and supports, of which educational resources comprise just a small fraction. Thus, our intentions focus more on the capacity of the resources to deepen student engagement, empower teachers, and ultimately enable greater creativity in education with less risk to those involved. By encouraging risk-taking and personalization, we believe that we will ultimately see improvements in learning outcomes as well.

Fortunately, our resources are getting widely used. On the Hippocampus site alone, we are getting approximately 250,000 unique visitors per month, consisting of over 8 million page views. More impressive is the time on site, which is averaging over 20 minutes per visitor. Though it is difficult to get accurate estimates, we believe that the offline usage via NROC Network members doubles those numbers. Unfortunately, though usage statistics are popular metrics for online sites, they offer little value when we are really interested in behavioral change and impact. Therefore, we have been working directly with some of our institutional members to gather more comprehensive data on outcomes as they have adopted and piloted the use of our resources. Teasing out which approaches are more or less effective is challenging, so our research has gathered both quantitative and qualitative measures from institutions that have been piloting our resources.

A. Research pilot implementations

We have initiated pilot studies with over 50 institutional partners for both Algebra and Developmental Math; however, most pilot studies are still under way. Several pilots have produced interim reports by mid-2012, allowing us to make some limited general observations and share some preliminary data.

In organizing the pilot studies, we strove for maximum variation in implementations, including diversity in district statistics (e.g., district enrollment, teacher FTE, years of NROC membership, learning management system in use, etc.) and in instructional designs (e.g., classroom-based instruction, blended/hybrid learning, accelerated courses, credit recovery, online independent study, individualized instruction, asynchronous learning, self-paced learning, online teacher-led remedial education, adult education, etc.). Thus far, the use cases for the resources themselves cover a wide spectrum, including:

- using the courseware as an optional supplement,

- as a required supplement to lecture, text, and or software,
- in a self-paced lab setting with a roaming teacher,
- as a completely online course.

For about 1/3 of teachers that participated in the pilot studies, this was their first time teaching with online materials. For Algebra, many of the teachers had received some training about teaching online or with technology, whereas almost none of the teachers involved with developmental math had received such training.

B. Research pilot outcomes

Our evidence for impact on student attitudes and teacher perceptions comes primary from feedback forms and interviews conducted by MITE staff. For developmental math, students self-reported a 50+% improvement in attitude, in which they say they like math more; moreover, 60+% feel they are now better at math (n=40). They report that the practice problems are most useful, followed by the worked examples and presentations. Students reported using the topic text (the integrated digital textbook) the least. For Algebra, 94% of the students reported that NROC materials helped them to be at least as good or better (35%) at math. Students repeatedly reported their appreciation in having additional control of their learning because the course is self-paced, meaning they could stop and repeat as much as needed. Students also reported they liked that NROC math was available online and that they had access both at home and at school. Finally, students often said that the presentations were easy to understand and engaging, and they liked receiving quick feedback throughout the lessons.

Teachers reported that they felt the course is well designed and has a logical progression. They also appreciated its adaptability, allowing them to move and add content. Many instructors noted the strong quality of teaching in the videos, giving them greater confidence in using the materials to augment or replace some of their lecture time. Most technically skilled instructors found the course "great and easy to use." Others cited the value of a mix of approaches, providing alternative ways for students to learn the material. Noting that developmental students are not usually excited about taking a math course, many instructors found that a single student's enthusiasm with the courseware can spread to the rest of the students. These findings, along with additional details and comments from pilot participants, are available at: www.nrocmath.org.

In working with our pilot institutions, we found that the key variables to successful integration of NROC materials were adequate teacher technical skills, equipment quality, bandwidth, and availability of local technical support. It is our impression that those pilots where instructors are using the NROC content as the main learning material are experiencing more success than those leaving the usage to student choice. This finding complements our perception that the NROC materials are at their best when the pedagogical focus is on student engagement and persistence, as opposed to test mastery. Some of the strongest evidence to date for this finding comes from one of our pilot case studies, at the Sierra Vista High School, detailed in the next section. The complete report for this case study is available at: http://nrocmath.org/product/k12/algebra-1/#whittier-union-high-school-district.

C. Sierra Vista Alternative School — challenging the status quo

The Sierra Vista High School (Sierra Vista) is part of the Whittier Union High School District (Whittier USD), in Whittier, CA. The district is located 10 miles south of Los Angeles, and includes six comprehensive high schools, one adult school, plus Sierra Vista. The school enrolled 469 students in 2009-10; 84% are Hispanic/Latino, and 62% are identified as socioeconomically disadvantaged. In addition, 62% of the students have credit deficiencies, 80% are teen parents, and 20% are homeless. While the school serves grades 9-12, the majority of the students are in grades 11-12, and many are 5th year seniors working to finish their high school degrees. Sierra Vista is a year-round, open enrollment high school that offers students flexible options for completing their high school degree. All of the

students that took part in the pilot were repeating Algebra, some for the third or fourth time.

The Whittier USD district uses standardized algebra benchmark unit tests as part of their requirements for high school graduation. The students in the pilot could be compared to students in a traditional textbook and lecture-based classroom on the basis of these tests. The pilot classroom took a hybrid-lab approach, where the NROC Algebra materials comprised the core learning materials, the class was self-paced, and the students had access to a teacher-coach at any time in the lab itself.

The nature of the online, hybrid class allowed students to easily enter the course at different times and participate when it best worked in their schedules. While continuation school students often have difficulty attending regular classes because of personal or social reasons, this hybrid class approach seemed to avoid many of these problems and attendance was higher than in the traditional class. Students also responded well to the flexibility and self-paced approach of the curriculum. The open entry/open exit policy helped keep students from falling behind, one of the primary reasons students drop out. Students worked at their own pace and were able to repeat sections until they mastered the material. The ability to repeat materials was especially beneficial for students who were reluctant or embarrassed to ask questions in class.

The teacher developed a plan that outlined student assignments, and then monitored student performance, corrected assignments, provided feedback and advice, and handled technical issues. Assignments included reading text and writing definitions; listening to presentations and responding to questions; and doing math problems online and on printed worksheets.

D. Sierra Vista Alternative School — outcomes

Preliminary results suggest that students in the hybrid class using the NROC Algebra 1 program are more likely to pass the algebra benchmark tests than students in the traditional course. Whittier USD as a whole (all high schools included) has a 75% passing rate for common assessment benchmarks. By comparison, the hybrid class using the Algebra 1 courseware had a passing rate of 88%. The first semester of the pilot, about 1/2 of the traditional classroom students passed the common assessment, while nearly all of the students in the hybrid class passed the same exam (see Figures 1 and 2). Based on student and instructor comments, one of the biggest factors that favored the hybrid class pertained to the different pacing and expectations of the courses. In the traditional class, the class had to stick to a schedule, which meant that students were forced to move on to new material regardless of whether all of the students were ready. In the hybrid class, by contrast, students didn’t move on until they were ready; the pace was sometimes slower, but the success rates were higher, and the students weren't nearly as frustrated with the experience.

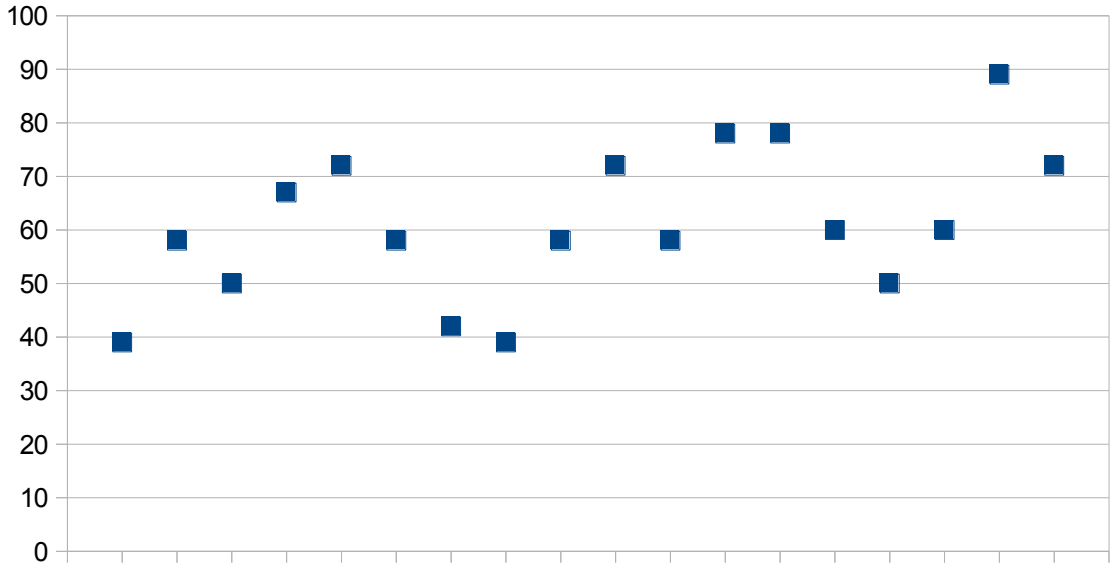

Figure 1. Whittier USD benchmark exam results for the traditional class: lecture-based and teacher-led classroom, with textbook; the entire class tests at the same time.

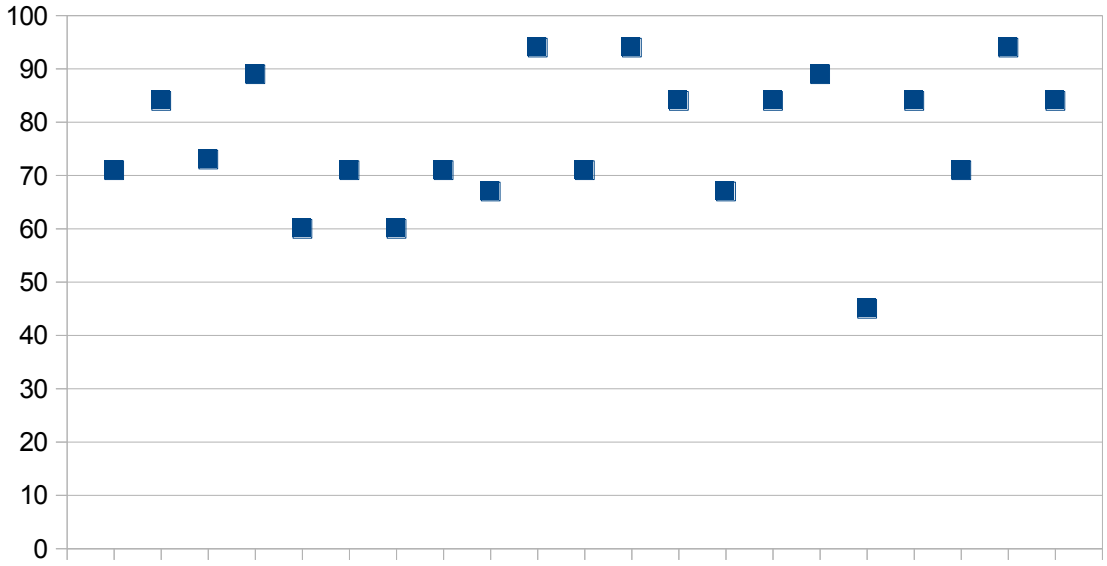

Figure 2. Whittier USD benchmark exam results for the hybrid class: NROC Algebra 1 materials as primary resource, and access to a computer lab with teacher support; students test when ready.

Overall, students were very positive about the NROC Algebra 1 courseware and their hybrid class. There were several reasons students preferred the hybrid class to traditional math classes:

- They liked working at their own pace and repeating material they did not understand.
- The courseware is flexible, so they could work on assignments in class, at home, or at the library.
- The multimedia content is more engaging than passively listening to a lecture.
- Students found that learning math was easier than they expected.

V. CONCLUSIONS

No amount or quality of resources will enable us to overcome the challenges to improving math educational outcomes in the United States—to expect such an outcome requires us to put too much emphasis on the importance of the resources in isolation from the myriad other factors at play. However, resources can certainly impede improvement, especially if they are of poor quality, inaccurate, or simply poorly suited to the needs of the teachers and students who use them. In a pre-digital world, mass customization was simply impossible. In a digital world, it is not only possible, but fairly common in sectors outside of education. The growth of OER reflects broad interest in bringing the capacities for personalization and sharing into the educational arena, but the impacts on learning and educational practice have been minimal to date.

MITE has strived to build a suite of resources that—at a minimum—meets the diverse needs of the nation's teachers and learners; ideally, our resources will do much more, facilitating and empowering those who are experimenting with more personalized and effective teaching and learning practices. It is too early to say definitively whether MITE's approach to production and distribution will be effective in these ways, but the initial evidence is promising. We hope that other institutions, teachers, and learners will give themselves permission to try new things, perhaps supported by NROC materials, or perhaps with other OER or digital media. Whether the experiments lead to incremental change or major shifts in practice, the time is now to embrace this potential. The status quo is too dismal to stand pat any longer.

VI. ABOUT THE AUTHOR

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